

## **Bioluminescence Potential in the Transition Zone to Very Shallow Water (VSW)**

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### **LONG-TERM GOALS**

The long-term goal is to advance our understanding of the ecology of bioluminescent organisms and the mechanisms governing the temporal and depth-dependent variability of bioluminescence in the coastal ocean. With improvements in technology, finer-scale resolution and concurrent physical, chemical and biological data are available to advance our understanding of the forcing mechanisms governing the temporal and depth-dependent variability of bioluminescence in environments of Naval relevance.

### **OBJECTIVES**

General patterns of bioluminescence potential in surface waters indicate that there is an increased signal in near shore waters. While present regional and coastal models are able to show this coastal enhancement, the model grids are not scaled to the physical dynamics governing the transition zone from the near shore to the shoreline. In addition, few measurements of bioluminescence have been made in this transition region because of limitations in both platforms and sensors. This is despite the stated need in a recent report (National Research Council 2003). The report highlights bioluminescence as an environmental variable that often influences planning and execution of naval missions, and, in general, the need for more understanding of littoral processes. The objective of this project is to better characterize bioluminescence in the transition zone from the near shore to very shallow water (VSW) environments. Measurements of bioluminescence and other parameters will be made in conjunction with other ONR-sponsored physical oceanographers and near shore modelers to provide a basis for a global understanding of how bioluminescent organisms respond in these turbulent and high shear environments. Specifically the objectives are to; 1) Focus measurements in the transition zones from the near shore to VSW environments (including the surf zone) in conjunction with other physical measurements. 2) Relate cross-shore and along-shore measurements to the shoreline types and shoreline morphologies, including entrances to ports and harbors over a range of relevant time scales (i.e. tidal). 3) Elucidate differential responses between autotrophic and heterotrophic organisms to turbulent and high shear environments.

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## APPROACH

The approach to address the primary objectives above was to take advantage of ongoing studies in California in collaboration with ONR-funded physical oceanographers (R. Guza, SIO; E. Thornton, NPS; Kelly Benoit-Bird), with specialties in the surf zone, near shore transition environments, and the ecology of marine zooplankton. One was in Huntington Beach, CA, and the others were in Monterey Bay. The primary focus of these studies was to examine the effects of offshore wave energy (where the depth is greater than  $1/20^{\text{th}}$  of the wavelength of the wave) as it propagates inshore and influences, near shore waves, shear/turbulence fields and along- and cross-shore flows. Temporal and spatial measurements of bioluminescence were made as part of these studies in a continuing effort to define the distribution of near shore bioluminescence (see below). In addition to these efforts, a continued effort to obtain a long time series of bioluminescence is ongoing as well as involvement in a number of ancillary ONR projects to address the long-term goals stated above.

## WORK COMPLETED

In order to address questions related to bioluminescence in the surf zone, the REMUS-100 vehicle the REMUS AUV platform equipped with a bioluminescence bathyphotometer (Blackwell *et al.*, 2002; Moline *et al.*, 2005) was deployed repeatedly in two locations; Huntington Beach, CA and Monterey Bay, CA. In Huntington Beach, CA, 6 bioluminescence missions were conducted from September 20<sup>th</sup> to October 7<sup>th</sup>, 2006. The mission grid was set up to examine the transition zone from the surf zone offshore and was 1.5 km by 0.5 km oriented alongshore. An initial survey of the location of breaking waves alongshore was made and used in setting up the grid. The grid entered the surf zone to the greatest extent in the northern corner. There was a gap in the grid around the in situ surf zone instrumentation. An onshore-offshore transect was also part of each mission to examine the vertical distribution of bioluminescence and currents in this region. In Monterey Bay, three deployments were made from May 19<sup>th</sup> through the 21<sup>st</sup>, 2007 off of San Francisco, CA. The deployment strategy was much like the one set up for Huntington Beach (see above), however the alongshore extent was reduced. The water depths within the programmed grid ranged from 11 to 4 m. During the deployment the vehicle was in 2 m water depth. The wave heights measured during the experiment were consistent at 2 m and normal to the angle of the beach (data not shown). The vehicle operated at 1 m during the 19<sup>th</sup> of May and was reprogrammed to 2 m on the two subsequent missions.

### *Complementary Studies*

Temporal measurements of bioluminescence have been ongoing in San Luis Obispo Bay. The vertical record from the automated profiler is now over 60 months long. Time series analysis is now being applied to this data set to elucidate the major forcing mechanisms leading to bioluminescent events. We were able to integrate into the Layered Organization in the Coastal Ocean (LOCO) ONR-DRI at the invitation of the PIs. For 8 successive nights, bioluminescence measurements were made with the AUV around the central study area in support of previous sampling objectives. Additionally, 3 additional sampling deployments were conducted in Monterey Bay in conjunction with K. Benoit-Bird acoustic measurements. Efforts to analyze these data and integrate within the larger study were successful and resulted in a number of publications (see below) and additional collaborations. As an aside, the REMUS AUVs in the Moline lab have now surpassed 5,000 km of underwater measurements, the majority related to the bioluminescence work and DOD related projects like this one. With the exception of the continued time series measurements, the field work of this program has ended and the focus continues to be on data analysis and reporting results.

## RESULTS

### *SURF ZONE BIOLUMINESCENCE*

Previous progress reports highlighted the field efforts from both the Huntington Beach 2006 and RIPEX 2007 Monterey Bay experiment. This was one of the first efforts to intentionally operate the UUV in and around the surf zone and establish operational performance in those conditions. Overall, despite some loss in the Long Baseline (LBL) signal to noise acoustic navigation, we established over the 9 missions that the REMUS could successfully operate in this environment, in a range of wave height conditions. Results from these efforts are currently being assembled for a publication. Briefly, decreases in bioluminescence were evident inshore despite continuous high bioluminescent phytoplankton loads. These measurements indicated a clear pattern of decreased bioluminescence within the surf zone transition. ADCP measurements taken in the center of the UUV operational box were used to generate a mean vertical shear profile, showing shear forces increasing toward the surface. As the vehicle was flying within these moderate shear forces ( $0.07\text{--}0.08\text{ N m}^{-2}$ ), we were able to quantify the effects on bioluminescence. Taking the Huntington Beach and Monterey Bay experiments together and relating the mean bioluminescence to the shear measured on the inshore edge of the AUV sampling grid, there was a significant relationship found, with the mean bioluminescence decreasing as a function of shear forcing. While this does not take into account the organismal loadings, chlorophyll a biomass indicated that these loads were relatively constant within studies. The fact that the Monterey Bay experiment showed the lowest bioluminescence with the highest chlorophyll biomass clearly shows this is a dynamic process and the relationship changes over timescales of minutes to hours.

### *THIN LAYERS*

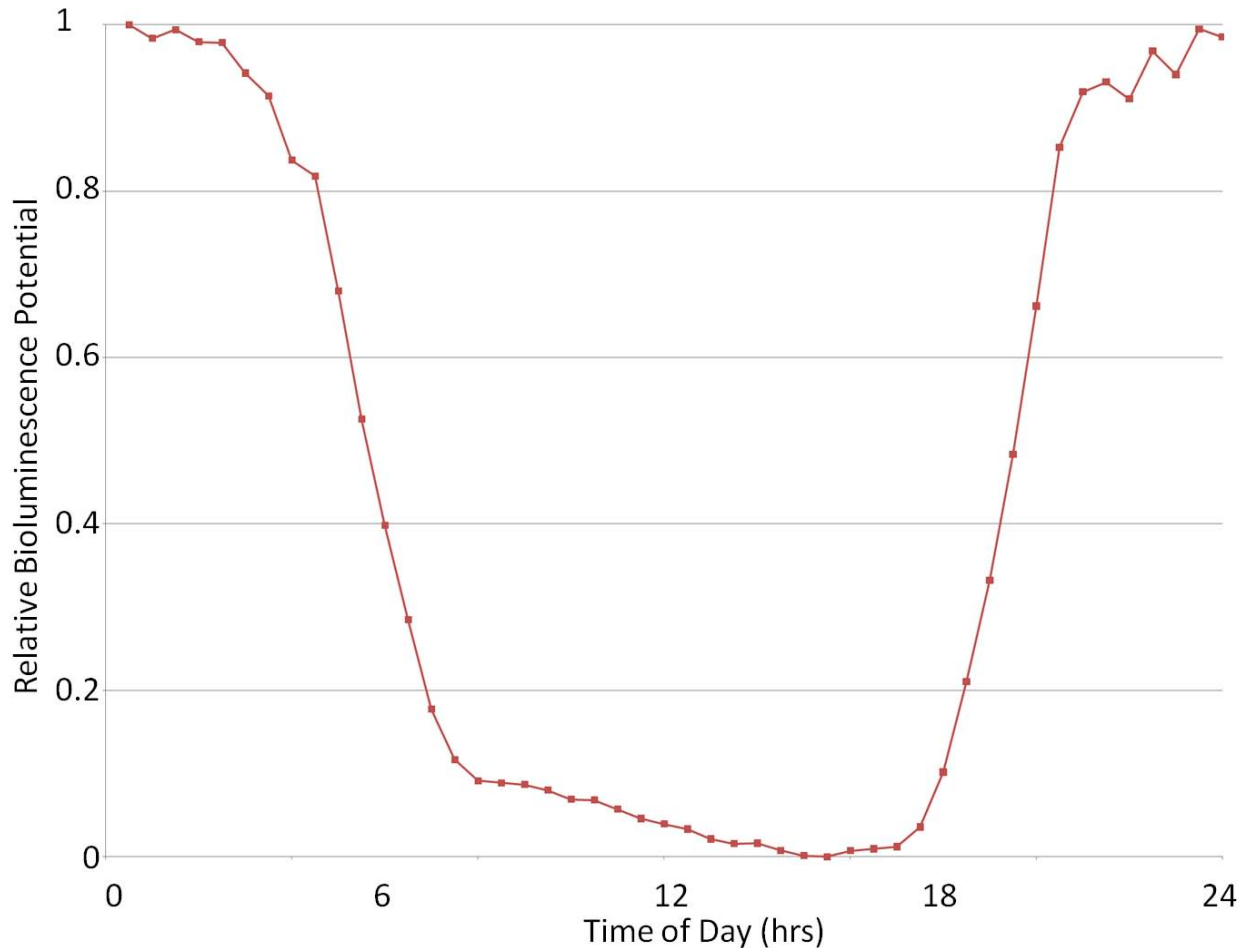
Integrated studies of thin layers at multiple trophic levels have been limited by the difficulties in making measurements of multiple sizes of organisms in meter-scale thick aggregations simultaneously at similar scales, the often disparate techniques (and thus investigators) needed for different organisms, and the challenges in quantitatively assessing layer associations. We were able to integrate into the Layered Organization in the Coastal Ocean (LOCO) ONR-DRI, a multi-investigator, interdisciplinary research initiative developed to overcome some of these challenges. The goal of our effort, a component of the LOCO program, was to examine the relationships between fluorescent, bioluminescent, and acoustically scattering layers in Monterey Bay in an effort to understand the interactions between adjacent trophic levels, assess the influence of bioluminescence on these interactions, and to elucidate potential mechanisms involved in the differential formation of these layers. We addressed these questions by combining measurements from multiple platforms with acoustic instruments on moorings and on a ship and optics on a profiler and the UUV in 2006 and 2008. The combination of data between these various platforms was designed to elucidate the multi-dimensional overlap of trophic levels found in and around thin layers.

In a set of companion papers (Benoit-Bird et al. 2010a, Moline et al. 2010, Sullivan et al. 2010), we show the combination of measurement approaches revealed a pattern in the relationship between the depth of phytoplankton and zooplankton thin layers that was consistent between study periods despite differences in platforms and deployment methodologies. Zooplankton thin layers were found in close proximity in depth to phytoplankton thin layers only when the fluorescence in the thin layer was greater than about 20% of the total water column integrated fluorescence. Previous studies have found phytoplankton and zooplankton layers overlap in some observations but not in others, something that has been difficult to understand in the context of predator-prey interactions. Our results support the conclusion that phytoplankton thin layers were accessible to zooplankton grazers and that zooplankton

did exploit these features. However, zooplankton did so only when food resources were otherwise limited. Swimming behavior in response to prey was clearly an important mechanism controlling the depth distribution of zooplankton thin layers but the factors leading to the formation of thin layers must have involved more than prey distribution as thin zooplankton layers occurred both in the presence and absence of phytoplankton thin layers. Our results suggest that zooplankton in thin layers have the ability to sense phytoplankton abundance not only in the vertical vicinity of a thin phytoplankton layer, but over the entire water column. These results highlight the value of integrating measurements of various types of organisms to understand processes in and around thin layers and the importance of assessing ecological interactions in plankton thin layers within the context of the properties of the entire water column, like the animals themselves do. In addition to elucidating the associations between these thin layers, we were also able to quantify the horizontal spatial scale of the thin layers using the ship data mentioned above and 6-years of UUV data collected in Monterey Bay (2002-2008). While the horizontal de-correlation length scales were related to the dynamic of each measurement made, there was a significant decrease in the de-correlation length scale over time, which coincides with a documented shift in the plankton community in Monterey Bay. This shift highlights the importance of considering plankton behavior and time of day with respect to scale, when studying layers. The changes in critical horizontal length scales also highlight the challenges of sampling these phenomena. New advances in sensors and autonomous underwater platforms hold great promise for better resolving the horizontal extent of optical and acoustical scattering layers in the coastal ocean. Also as a part of this study, we revealed that open fluorometers (with blue LEDs of equivalent wavelengths to bioluminescent) influence the behavior of certain species of zooplankton. This work was also published recently (Benoit-Bird et al. 2010b).

#### *TIME SERIES PROFILER*

In May, 2005, the automated profiler on the Cal Poly pier in San Luis Obispo Bay began operation and with intermittent breaks, it has been profiling continuously since then. The profiler has been set to measure the vertical structure of bioluminescence potential in conjunction with physical variables every half hour. Elevated levels are consistent with the phytoplankton growth period in April/May and again in August/September. Very high values are associated with late season dinoflagellate blooms occurring during atmospherically quiescent periods with high solar insulation. Over the period of performance, there have been periods without data were due to power interruption to the profiler, cable replacement and an upgrade from a generation-2 sensor to a generation-3 sensor, in collaboration with UCSB. The profiler has been recently upgraded and has the following instrumentation; 3 BP units, a transmissometer, fluorescence, backscatter, CTD and 2 plankton samplers. Time series analysis of the data is ongoing to examine the seasonal growth patterns, periods of local advection events, and separation of autotrophic and heterotrophic plankton communities. These time series measurements are being applied in two areas. The first is to examine the seasonality to predict a period of high bioluminescence with high probability. This is for a field exercises at the pier facility to model water leaving radiance from a source target in support of developing a tactical bioluminescence aid in collaboration with Wetlabs (STTR). The second use has been to closely examine diel periodicity in bioluminescence. While it has been well characterized in the lab, few studies have characterized it in the field and none for this period of time. The motivation for this effort is to develop a time dependent quenching function for future model runs to account for the diel periodicity of bioluminescence. This is part of another project (N00014-09-1-0548) where we will incorporate this diel rhythms of bioluminescence intensity in the model for dynamic predictions of bioluminescence water-leaving radiance (Figure 1). Although this has been shown in many studies, a systematic evaluation and influence of depth, irradiance, and seasonality has yet to be done. We are currently preparing a manuscript on this subject.



***Figure 1. The relative response of bioluminescence potential as a function of time over a day. Data were derived from over 5 million observations of bioluminescence potential measured by the automated profiling system in San Luis Obispo Bay, CA. The mean observations from each profile were normalized to the minimum and maximum and then pooled to generate this characteristic pattern of diel periodicity for this latitude and coastal environment. The influence of day length, depth, and community-level periodicity are integrated here but are currently being evaluated and quantified separately.***

## **IMPACT/APPLICATION**

Deployments are detecting patterns in the surf transition zone that have not previously been examined. This is also true for the continuing temporal data set. Integration into other existing programs also provides additional opportunities to examine bioluminescence patterns, structuring mechanisms and potential impacts (i.e. organismal/Naval). Here data show that bioluminescence decreases in the surf zone, which may influence nearshore VSW operations and decision-making. In high energy environments, the surf zone and rip channels may be opportunities for safer ingress and egress. Results supported by this study are currently being examined for integration into a Bio-Optical module being developed for the Navy's NCOM model by NRL.

## TRANSITIONS

This project adds a high-resolution nighttime bioluminescence capability to an existing network designed to predict the 3-dimensional structure of coastal currents in the surf zone and transition zone. Fine-scale vertical bioluminescent measurements coupled with ancillary physical/biological measurements will improve the ability to predict bioluminescent events in the near shore littoral regions of interest to Naval operations and tactical mission planning. The sensors developed through S&T funds and used in this study are currently in transition by industry (Wetlabs) under an STTR to the operational Navy.

## RELATED PROJECTS

1 – This project was conducted in conjunction with two near shore State supported programs in California. Surf zone and transition zone data will be analyzed in collaboration with R. Guza and E. Thornton. 2 –An STTR project in collaboration with C. Orrico, R. Zaneveld, and A. Barnard (Wetlabs) is using the pier-based profiler to evaluate seasonality of bioluminescence for development and testing of a new tactical bioluminescence sensor. 3 – Data from this project also allowed for the characterization of the natural diel periodicity of bioluminescence to be used in incorporating bioluminescence in the Navy NCOM model (N00014-09-1-0548)

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The following papers were partially or fully supported by this grant award:

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